

Using Diffraction Enhanced X-ray Imaging to Detect Articular Cartilage

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Introduction: Destruction and loss of articular cartilage is one of the key events in osteoarthritic disorders. Imaging techniques commonly used to assess articular cartilage are based on x-ray, ultrasound or nuclear magnet resonance (1, 2). Conventional radiography has the highest spatial resolution (3) and is the initial and most abundantly used imaging method in joint abnormalities. The radiographic evaluation is based on narrowing of the joint space between the ends of the bones that occurs as cartilage is destroyed. Therefore, conventional radiography is sensitive only in cases of advanced disease. The cartilage tissue itself is not visible, and focal cartilage defects or structural abnormalities diagnostic of early stages of the degenerative joint disease are generally not seen on conventional radiographs or x-ray computerized tomography. Diffraction Enhanced Imaging (DEI) is an x-ray radiographic technique, which derives contrast from x-ray refraction and extinction in addition to the absorption mechanism of conventional radiography. These new contrast sources can in some cases allow visualization of tissues and features that are not possible using conventional means. We report in this study that we are able to image human articular cartilages with DEI. In addition, we can detect structural features within cartilage that appear to represent degenerative changes particularly evident in cartilages from osteoarthritic patients.

Methods and Materials: The knee and ankle articular cartilages used for this study were obtained with institutional approval either from donors through the Regional Organ Bank of Illinois or from patients undergoing total knee replacements. All experiments were performed at the X15A beam line at the National Synchrotron Light Source, Brookhaven National Laboratory. The basics of DEI have been described elsewhere (4, 5, 6); however, briefly, the method uses highly collimated X-rays prepared by x-ray diffraction from perfect silicon crystals. These collimated x-rays consist of a single X-ray energy and are used as the beam to image the object. Synchrotron radiographs are taken using this beam. For DEI, a crystal is placed after the object to further process the beam. This crystal is called the analyzer. If this crystal is rotated through the Bragg condition for diffraction, the intensity from the crystal traces out a profile that is called the rocking curve. This profile is roughly triangular and has peak intensity close to that of the beam intensity striking the analyzer crystal. The character of the images obtained change depending on the setting of the analyzer crystal. The cartilages were x-rayed in a posterior to anterior direction.

Results: With conventional radiography, the articular cartilage is not visible; however, when DEI is used, the normal articular cartilage appears homogeneous and of moderate density. The appearance of cartilages from osteoarthritic human knees is not homogeneous (Figure 1). The remaining cartilage from an osteoarthritic human knee can barely be detected in the conventional synchrotron radiography mode (A); however, it can be clearly detected and distinguished from the bone in the DEI-setup (B).

Of special interest are the thin white lines seen within the osteoarthritic cartilage. It is possible that those white lines represent structural alterations, which give rise to specific refraction patterns and extinction effects. These are unique to DEI compared to conventional radiography, which only sees absorbance as a contrast mechanism. This would most likely develop at the edges of cartilage fibrillations, fissures or defects. Alternatively, the structures could represent rearrangement of macromolecular components. It may also well be that condensed collagen fibrils cause such effects. The contrast may be further enhanced by the loss of normally entrapped large proteoglycans or by secondary mineralization. Their exact composition is unknown at the present time.

Conclusions: We have shown that it is possible to derive high-resolution images of human articular cartilage on a radiograph using a new x-ray modality, called DEI. This new technology could provide scientists and clinicians with information about the internal structure of osteoarthritic cartilage, and even more important, identify early cartilage degeneration before any clinical evidence of disease has evolved. By comparing the magnified images with the gross pathology and light microscopy, a link could be seen between the image at the lesion site and the severity of damage. DEI may open the door to a new means of early diagnosis and treatment for osteoarthritic disorders. We believe that DEI can be used as a part of a new x-ray generation in research as well as in clinical radiology, especially in skeletal X-ray, and in other areas where soft tissue contrast needs to be enhanced.

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